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(54) **DUAL MANIFOLD SYSTEM AND METHOD FOR FLUID TRANSFER**

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(52) **U.S. Cl.** ..... **436/180**; 436/174; 422/100; 73/864.17; 73/863.32; 73/864; 73/864.01; 73/864.02; 73/864.11

(58) **Field of Search** ..... 422/100; 436/180, 436/174; 73/864.17, 863.32, 864, 864.01, 864.02, 864.11

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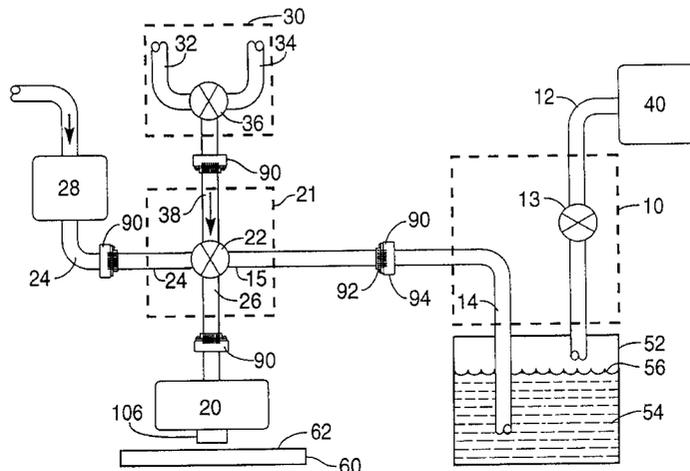
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(57) **ABSTRACT**

A dual-manifold assembly is provided for the rapid, parallel transfer of liquid reagents from a microtiter plate to a solid state microelectronic device having biological sensors integrated thereon. The assembly includes aspiration and dispense manifolds connected by a plurality of conduits. In operation, the aspiration manifold is actuated such that the aspiration manifold is seated onto an array of reagent-filled wells of the microtiter plate. The wells are pressurized to force reagent through conduits toward the dispense manifold. A pressure pulse provided by a standard ink-jet print-head ejects nanoliter-to-picoliter droplets of reagent through an array of printhead orifices and onto test sites on the surface of the microelectronic device.

**9 Claims, 7 Drawing Sheets**



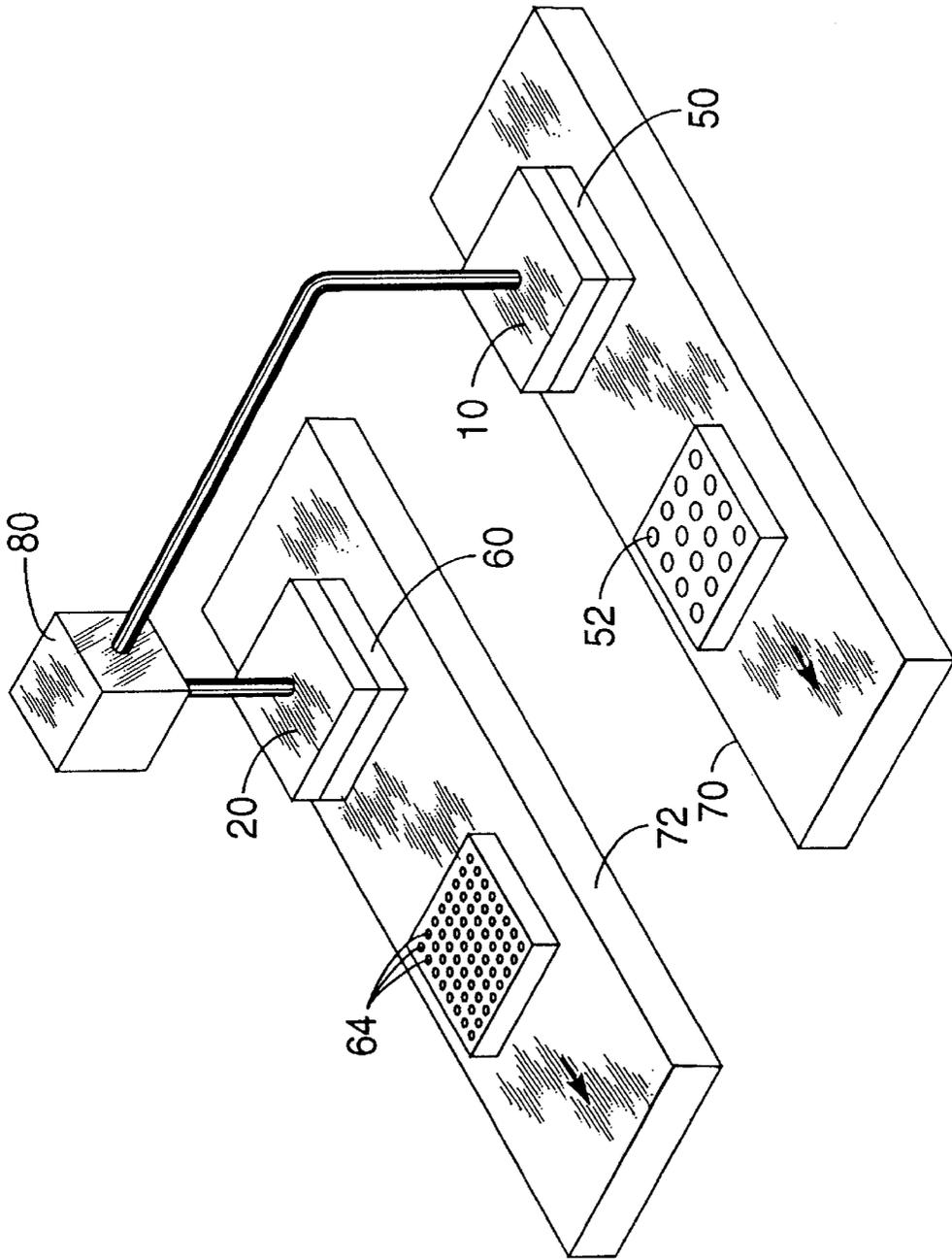


Figure 1

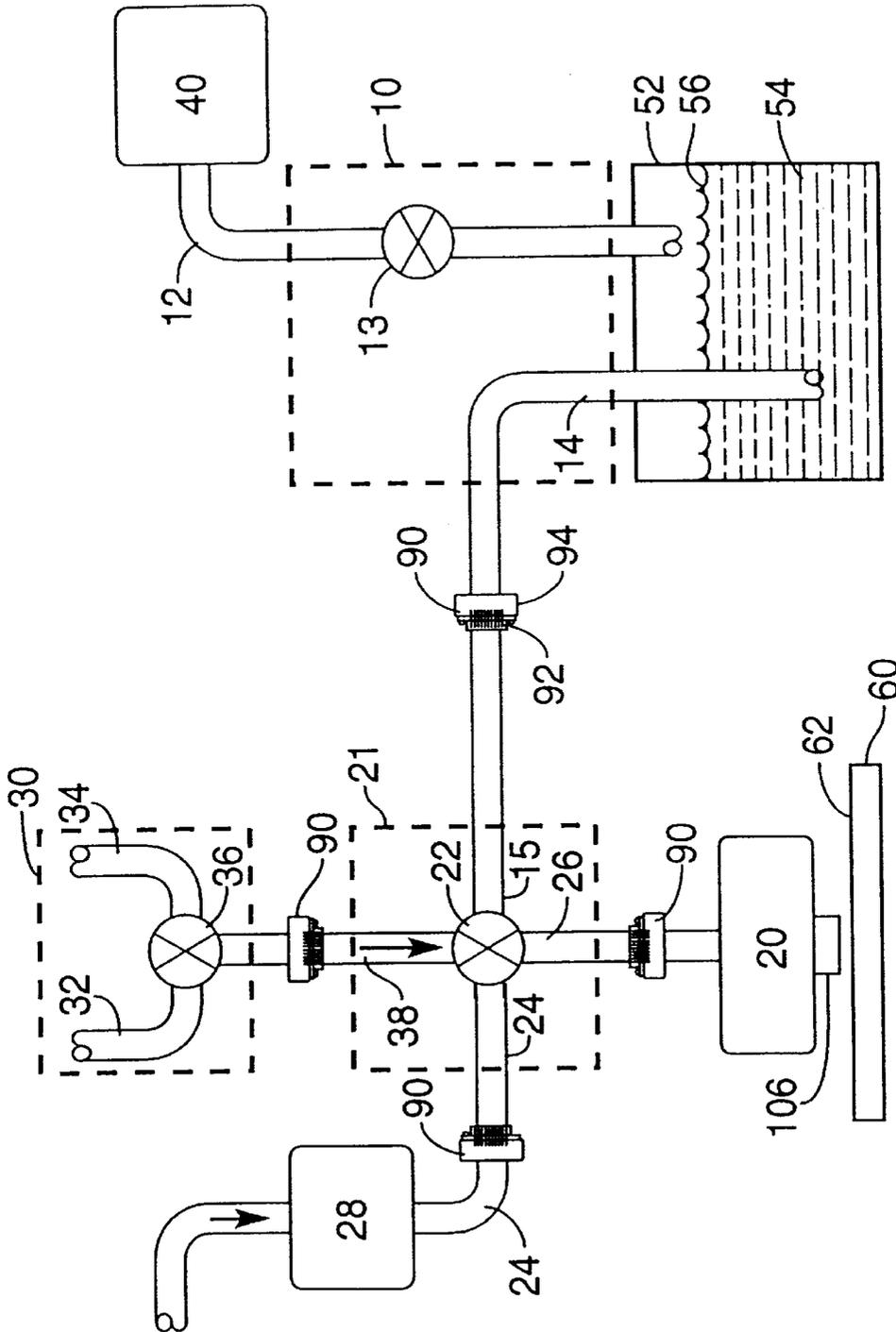


Figure 2



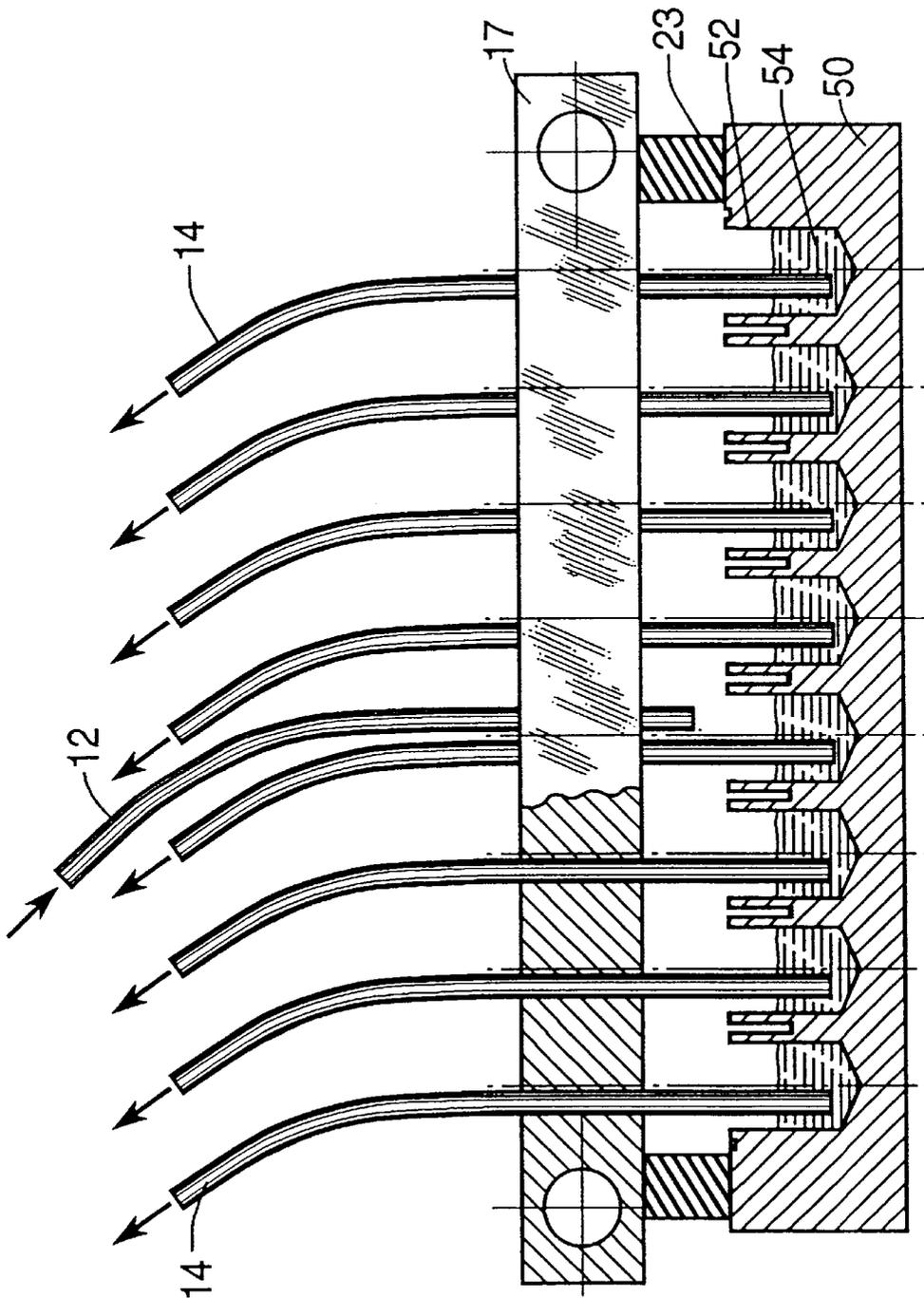


Figure 4

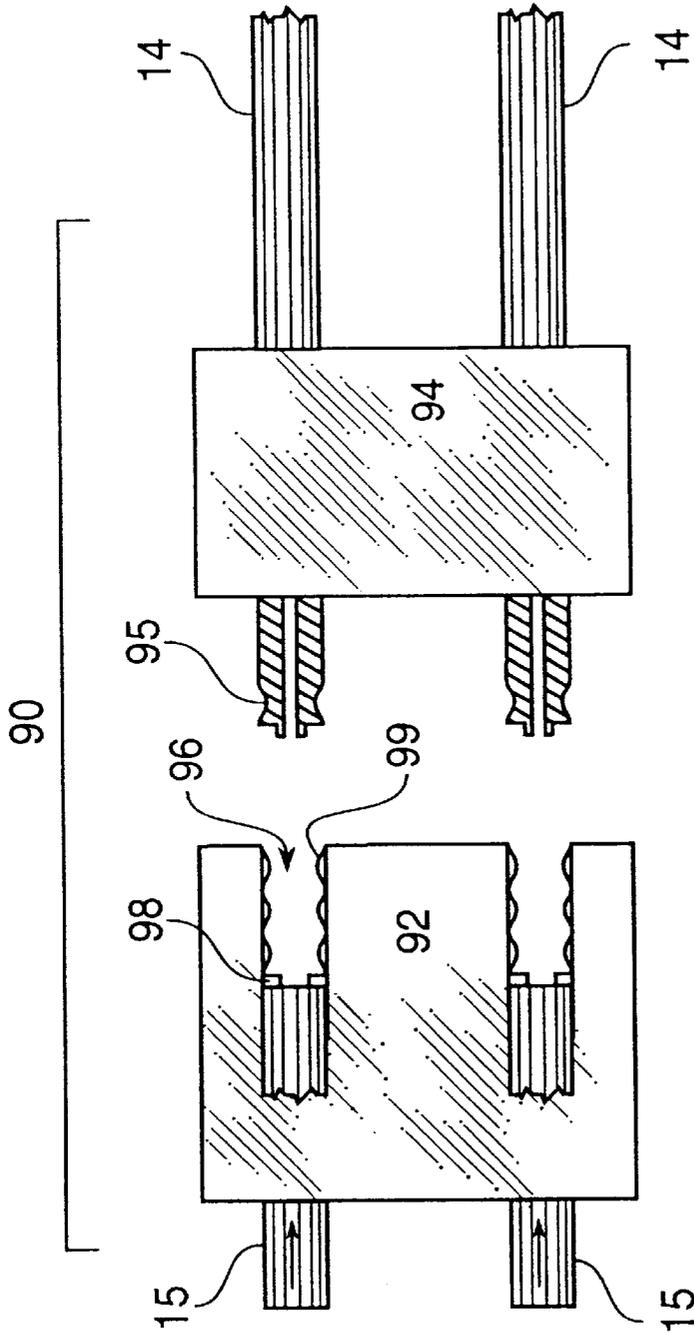


Figure 5

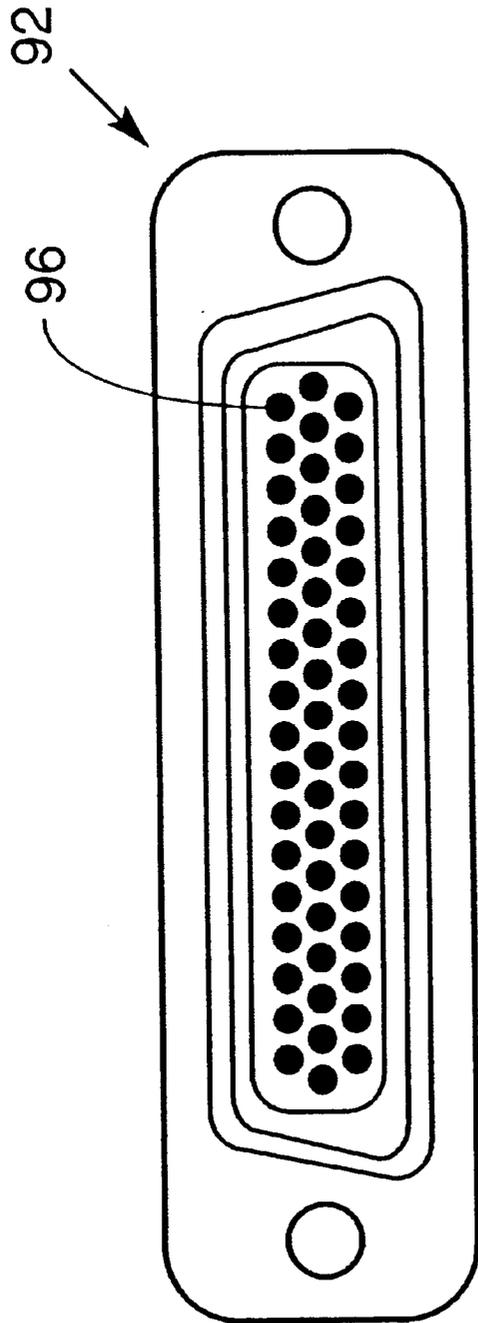


Figure 6

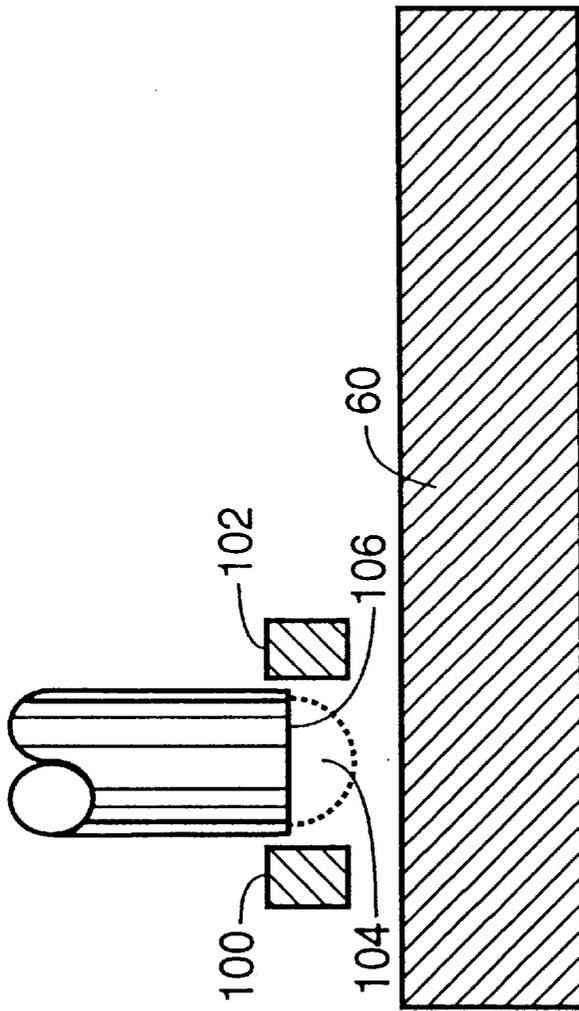


Figure 7

## DUAL MANIFOLD SYSTEM AND METHOD FOR FLUID TRANSFER

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional patent application of U.S. patent application Ser. No. 09/262,455, filed on Mar. 4, 1999.

### STATEMENT REGARDING FEDERALLY- SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with government support under contract DE-AC05-96OR22464, awarded by the United States Department of Energy to Lockheed Martin Energy Research Corporation, and the United States Government has certain rights in this invention.

### FIELD OF THE INVENTION

This invention relates generally to an apparatus and method for fabricating microarrays of biological samples on a support substrate, and more particularly to a dual manifold system for the rapid, parallel transfer of reagents to test substrates for large-scale screening assays.

### BACKGROUND OF THE INVENTION

In clinical chemistry, it is frequently necessary to carry out the metered application of an analytical liquid to a target. One case which is particularly relevant to the present invention is the application of the analytical liquid to an analysis element such as a chip-based biological sensor in which biological materials are integrated with microelectronic devices. In recent years, rapid technological advances have enabled the use of micro-scale chemical/biochemical reactions for performing various types of analyses. For instance, DNA microarrays such as genosensors allow thousands of samples to be assessed simultaneously on a microelectronic test chip that is less than one-quarter of an inch in length per side. Typical test sites on such a chip are on the order of about 100 microns ( $\mu\text{m}$ ) in diameter. Conventional applications of chip-based biological sensors include mutation diagnosis, organism identification and gene expression profiling. More recent applications, such as parallel screening of chemical compounds for drug discovery and protein arrays for functional analysis, will soon be routine.

Known fluid handling systems for dispensing, or "micro-spotting", arrays of biological materials on a target substrate commonly comprise pick-and-place equipment. Generally, pick-and-place dispense systems include a dispense head adapted for transferring volumes of fluid from a fluid source to a target substrate. The time required to pick up, transfer and deposit a given volume of liquid significantly limits the efficiency of pick-and-place systems for micro-spotting. This lack of efficiency is even more pronounced where the target substrate contains hundreds, or even thousands, of test sites. Efforts have been made to improve the efficiency of pick and place systems for micro-spotting. For instance, systems have been adapted for picking up, transferring and depositing multiple sample volumes simultaneously. However, the time required for dispense head movement remains a significant limitation of such systems.

Furthermore, the multiple degrees of freedom associated with the movement of individual system components, such as the dispense head, significantly limits the positional accuracy of samples deposited on a target substrate. In instances where the equipment is adapted for contact dis-

pensing (i.e., where the dispense elements of the system physically contact the target substrate to effect transfer of the fluid to the target substrate) such limitations may be magnified. In particular, dispense tip deformation can lead to irregular sample spacing and, in some instances, cross-contamination of adjacent test sites.

Due in part to the aforementioned limitations, the positional accuracy and liquid transfer volume capability of conventional pick-and-place dispensing systems can not meet the requirements of many evolving applications. Constructing microarrays having a higher degree of miniaturization will require an increase in test site array density. Realizing such an increase in density will require a reduction in sample spot size and spot pitch (i.e., the center-to-center distance between adjacent deposits). In order to achieve such miniaturization, a fluid handling system capable of accurately and efficiently depositing chemical and biochemical reagent droplets having volumes on the order of picoliters is required.

Technology for dispensing liquid volumes on the order of picoliters exists, but has been primarily limited to the field of ink-jet printing. Many drop-on-demand ink-jet ideas and systems were invented, developed, and produced commercially in the 1970s and 1980s. A detailed and comprehensive summary of state-of-the-art drop-on-demand ink-jet printing technologies, including the fabrication of ink-jet valves and printheads, is provided in a published article by Hue P. Le, entitled Progress and Trends in Ink-jet Printing (Journal of Imaging Science and Technology, Volume 42, Number 1, pp. 49-62)(1998).

There is an established need for an apparatus and method for accurately and efficiently transferring and depositing, or printing, microarrays of reagent samples having volumes on the order of picoliters on a test substrate. It would be desirable to have a microarray printing apparatus for performing large-scale chemical/biochemical screening assays, wherein the system incorporates known drop-on-demand ink-jet printing technology and is particularly suited for dispensing chemical and/or biochemical reagents.

### SUMMARY OF THE INVENTION

It is an object of this invention to provide a liquid transfer apparatus capable of accurately and efficiently transferring liquid reagents from an array of reservoirs to an array of sites on a target substrate

It is another object of this invention to provide a liquid transfer apparatus capable of accurately and efficiently depositing volumes of liquid reagents in the range of about  $(10)^{-12}$  to about  $(10)^{-6}$  liters.

It is another object of this invention to provide a liquid transfer apparatus capable of effecting such reagent transfer with minimal movement of the apparatus during operation.

It is another object of this invention to provide a liquid transfer apparatus employing non-contact dispensing.

It is another object of this invention to provide a liquid transfer apparatus and method adapted for the automated printing, or micro-spotting, of multiple analytical chips in succession for performing large-scale screening assays.

These and other objects are achieved with the assembly and method of the present invention. Briefly, according to the invention, a dual-manifold assembly generally includes an aspiration manifold **10**, a dispense manifold **20**, and fluid transfer elements **80** for the parallel transfer of fluids therebetween. Although the apparatus and method are adaptable for use transferring a variety of liquids to a variety of target

substrates, in the preferred embodiment of the invention the apparatus is particularly suited for transferring chemical or biochemical reagents from an array of microtiter plate wells to an array of test sites on a chip-based biological sensor.

The aspiration manifold **10** is positioned above a source plate **50**, such as a microtiter plate, and is adapted for simultaneously aspirating liquid, such as a chemical reagent, from an array of reservoirs **52**. In the preferred embodiment of the present invention, the aspiration manifold includes an array of aspiration manifold subassemblies extending through a base plate **17** and adapted for being received by an array of reagent-filled wells **52**. When the aspiration manifold is seated onto the microtiter plate **50**, each subassembly seals a single well such that fluid communication to and from the well is limited to a pair of conduits **12**, **14** extending into the well. In operation, each well is pressurized by a pressure source **40** through conduit **12** which urges the liquid **54** through conduit **14** toward dispense manifold **20**. In an alternate embodiment of the invention, the aspiration manifold has a gasket element **23** for sealing against the periphery of the microtiter plate **50** during operation, precluding the need to pressurize the wells individually. In this alternate embodiment, pressurization of the wells **52** is accomplished through a single pressure conduit **12** extending through base plate **17**.

In the preferred embodiment of the invention, a plurality of aspiration conduits communicate with the dispense manifold side of the assembly through a modular connector **90**. Generally, the modular connector includes a male component **94** which releasably engages a female component **92**. Preferably, the aspiration conduits **14** terminate at component **94** which has integral tips **95** adapted for receipt by female component **92**. Preferably, the female component **92** of the modular connector is integrated into valve assembly **21**. Conduits **24**, **26** and **38**, of valve assembly **21**, can also be adapted for modular connection with other subassemblies of the dual manifold system. For instance, although dispense manifold **20** can be directly integrated into valve assembly **21**, in the preferred embodiment of the invention dispense manifold **20** is adapted for modular connection to valve assembly **21**.

Volumes of reagent in the range of about  $(10)^{-12}$  to about  $(10)^{-6}$  liters are ejected from the dispense manifold through an array of dispense manifold orifices **106** upon application of a force, such as a pressure pulse. Preferably, a pressure pulse is provided by a valve **28** incorporating ink jet style drop-on-demand technology. Valve **28** may be adapted for modular connection to valve assembly **21** or, alternatively, valve **28** may be directly integrated into the valve assembly. In the preferred embodiment of the invention, the dispense manifold **20** comprises a standard ink-jet style printing head having micro-machined channels each terminating at an orifice **106**.

In an alternate embodiment of the invention, a purging apparatus **30** is provided for periodically purging the assembly. Purging apparatus **30** includes gas and cleaning liquid inlets, **32** and **34** respectively, controllable through a solenoid or other suitable valve **36**. Preferably, purging apparatus **30** is adapted for modular connection to valve assembly **21**. Alternatively, apparatus **30** can be directly integrated into the valve assembly.

In further embodiments of the invention, auxiliary features are included for improving registration and alignment of reagent samples deposited on the test chip. In particular, fiducial pins and/or marks are integrated into the target substrate. The integrated features are sensed by a conven-

tional vision system for ensuring proper alignment and orientation during operation.

In yet a further embodiment of the invention, detection means are provided for detecting the passage of a droplet **104** of reagent from a dispense orifice **106**. The detection means may comprise optoelectronic devices, such as a photodiode **100**/photodetector **102** pair positioned near each orifice. Alternatively, electronic conduction-based sensors can be integrated into the dispense manifold.

In operation, microtiter plate **50** is positioned below the aspiration manifold **10** and the aspiration manifold is subsequently seated onto the plate such that an air-tight seal is formed between the aspiration manifold and the plate. Microtiter plate wells **52** are pressurized by a pressure source **40** through at least one conduit **12** to effect the transfer of reagent through a plurality of conduits **14** and into dispense manifold **20** positioned above target substrate **60**. Subsequently, a pressure pulse from valve **28** is communicated to the dispense manifold **20**, effecting the transfer of a desired volume of reagent through orifice **106** to test sites **64** on target substrate **60**. Further embodiments of the method include aligning the target substrate to ensure proper positioning of the reagent deposits, detecting the passage of reagent samples from the orifices of the dispense manifold, and purging the system between deposition, or printing, operations.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic of the major components of a dual manifold assembly in accordance with the present invention;

FIG. **2** is a schematic of a particular arrangement of subcomponents of a dual-manifold assembly in accordance with a preferred embodiment of the present invention;

FIG. **3** is a side view, partially in cross-section, of an aspiration manifold in accordance with a preferred embodiment of the present invention;

FIG. **4** is a side view, partially in cross-section, of an aspiration manifold in accordance with an alternate embodiment of the present invention;

FIG. **5** is a top view, partially cut away, of a preferred modular fluid connector in accordance with the present invention;

FIG. **6** is a front view of a female connector element of the modular fluid connector in FIG. **5**;

FIG. **7** is a cross-sectional view of a droplet ejection detection apparatus in accordance with an alternate embodiment of the present invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIGS. **1** and **2**, a dual manifold assembly is provided for the rapid, parallel transfer of liquid from an array of reservoirs **52** to a target substrate **60**. It will be apparent to one skilled in the art of microarray printing that the apparatus of the present invention lends itself to a variety of applications. Generally, the assembly is capable of transferring liquids from virtually any type of reservoir—including tubes, bottles and other liquid containers—to virtually any type of substrate. However, in the preferred embodiment of the present invention the assembly is particularly suited for transferring chemical or biochemical reagents from an array of wells **52** of a conventional microtiter plate to an array of test sites **64** on a chip-based biological sensor (commonly referred to in the art as a “microarray”) for performing screening assays. The assem-

bly is adaptable for printing arrays wherein the distance between adjacent test sites, or test site pitch, is in the range of about 1 micron ( $\mu\text{m}$ ) to about 10,000 microns ( $\mu\text{m}$ ).

The assembly includes aspiration and dispense manifolds, **10** and **20** respectively, separated by fluid transfer elements (generally denoted by reference numeral **80**). In operation, the dual-manifold assembly is adapted for the automated printing of multiple analytical chips in succession. Preferably, a conventional microtiter plate feeder **70** is employed for advancing a series of microtiter plates beneath the aspiration manifold **10**, and a target chip track **72** is employed for advancing test substrates **60** beneath the dispense manifold **20**. Although the term "advancing" is used to describe movement of the tracks **70**, **72**, the invention is not intended to be so limited. In particular, either or both of the tracks can be adapted for movement in multiple directions.

In the preferred embodiment of the invention, the assembly is adapted for transferring reagent from a given number of reservoirs **52** to an equal number of test sites **64** and, accordingly, the assembly is designed for the one-to-one transfer of liquid, i.e., from each reagent reservoir to a designated test site. However, the flexibility of the present invention lends itself to numerous variations of the preferred use. In particular, the assembly can be configured for transferring liquid from a given number of reservoirs to a different number of test sites. For instance, the dispense manifold **20** can be designed such that liquid samples from multiple aspiration reservoirs are combined and dispensed on a single test site. Conversely, the manifolding can be adapted for depositing liquid from a single reservoir to multiple test sites.

A preferred embodiment of the dual-manifold assembly of the present invention is schematically illustrated in FIG. 2. Although the assembly is adapted for simultaneously transferring multiple volumes of liquid reagent to multiple chip test sites, a clearer understanding of the invention can be gained through a description of the operation of the assembly with respect to the transfer of reagent from a single reservoir **52** to a single test site on target substrate surface **62**. Accordingly, FIG. 2 intentionally depicts a single set of fluid transfer elements. A pneumatic source **40** provides controlled pressure to reservoir **52** through a conduit **12** extending into the reservoir, with conduit **12** terminating at a position above liquid level **56**. The magnitude and duration of the pressure supplied to the reservoir can be adjusted by aspiration manifold valve **13**. Valve **13** is preferably a solenoid valve; however, other suitable valves are contemplated. For instance, other suitable valves may include shear valves, flat face valves and pinch valves, actuated by mechanical, electrical or pneumatic means. Upon application of pressure to the reservoir, liquid **54** is urged into and through aspiration conduit **14**. In the preferred embodiment of the invention, conduits **12** and **14** comprise narrow-bore plastic tubing having an inner diameter preferably ranging from about 0.020 mm to about 2.0 mm. However, the conduits can be manufactured from other suitable materials capable of transferring the desired fluids without being degraded, including, but not limited to, metals and glass.

In the preferred embodiment of the present invention, the aspiration manifold and dispense manifold sides of the assembly communicate through at least one modular fluid connector **90**. In particular, aspiration conduits **14** are bundled together and combined in a male component, or plug **94**, adapted for releasably engaging a female connector portion **92**. Alternatively, as will be apparent to one skilled in the art, the aspiration conduits could be combined in a

female plug adaptable for connection with a male component. The structure of a preferred modular connection is described in more detail below; however, numerous variations are possible without departing from the spirit and scope of the invention. Furthermore, although the modular connector **90** is depicted attached to a conduit **15** extending away from valve assembly **21**, it is preferred that the female connector portion **92** is integrated directly into valve assembly **21**. In this manner, the assembly of the present invention is adaptable for the simple and efficient attachment to myriad different aspiration manifold designs. In other words, regardless of the structure of the aspiration manifold, the aspiration conduits are combined in a standard connector or plug **94** adapted for releasably engaging female connector portion **92**. Thus, by integrating connector **92** into the valve assembly **21**, a single valve assembly **21** can be modularly connected to a variety of aspiration manifolds having different geometries, dimensions, and structures.

Valve assembly **21** includes a dispense manifold switching valve **22** which is preferably a flat face valve; however, other suitable valves are contemplated including, but not limited to, shear valves, solenoid valves and pinch valves, actuated by mechanical, electrical or pneumatic means. Switching valve **22** is fluidly connected to an ejection means **28** for advancing liquid through channels (not shown) in the dispense manifold **20**, to effect the ejection of a desired volume of the liquid onto the test substrate. Preferably, the ejection means delivers a pressure pulse having a pressure ranging from about  $6.9(10)^3 \text{ N/m}^2$  to about  $138(10)^3 \text{ N/m}^2$ , and having a duration ranging from about  $(10)^{-6}$  seconds to about  $(10)^{-2}$  seconds. In the preferred embodiment of the invention, the ejection means **28** comprises a conventional ink-jet style printing valve or pump designed for drop-on-demand printing. Ink-jet style printing valves/pumps for drop-on-demand printing, including thermal, solenoid and piezoelectric types, are commercially available and well known in the art. For instance, the Lee Company of Essex, Connecticut manufactures a solenoid-based ink-jet valve (Model No. INKX0502600AB) which is suitable for use with the present invention. Although ejection means **28** is shown connected to valve assembly **21** via a conduit **24**, the ejection means can be adapted for releasable attachment to the valve assembly, via a modular connector **90**, in a manner similar to the preferred aspiration manifold connection. Furthermore, alternate valve arrangements are possible. For instance, an ink jet valve/pump **28** can be directly integrated into valve assembly **21** via conduit **26**.

The incorporation of ink-jet drop-on-demand printing technology into the dispense assembly of the present invention provides significant advantages vis-a-vis known systems for printing microarrays. In particular, the ability to deliver the short-duration pressure pulses associated with ink-jet print valves enables the non-contact delivery of reagent sample volumes in the range of about  $(10)^{-12}$  to about  $(10)^{-6}$  liters. Upon application of a pressure pulse, at least one droplet of reagent is ejected through dispense manifold orifice **106** onto surface **62** of test substrate **60**. As used herein, the term "non-contact" refers to the lack of contact between the dispense manifold and the target substrate during deposition. In the preferred embodiment of the invention, liquid is communicated through channels micro-machined into an ink-jet style printhead—such as those commonly used in desktop and industrial printers—and each terminating at an orifice **106**. Depending upon the particular application, the orifices **106** can have diameters ranging from a minimum of about 1 micron ( $\mu\text{m}$ ) to a maximum of about 200 microns ( $\mu\text{m}$ ). In the preferred embodiment of the

invention, the dispense manifold **20** is adapted for releasable attachment to the valve assembly **21** via a modular connector **90**. Furthermore, the modular connector can be integrated directly into switching valve **22**. In this manner, the dispense manifold **20** can be fitted with a male connector portion **94** adapted for direct attachment to switching valve **22**, precluding the need for conduit **26**.

As previously discussed, liquid transferred from a reservoir on the aspiration side of the liquid transfer assembly can be manifolded in such a manner that the liquid is ejected through multiple orifices on the dispense side of the assembly. Conversely, liquid from multiple reservoirs on the aspiration side of the assembly can be combined and ejected through a single dispense orifice. The manifold assembly of the present invention also enables liquid to be transferred from a quantity of reservoirs to a quantity of test sites less than, equal to, or greater than the number of reservoirs. Accordingly, the array of printhead orifices can be dimensioned differently, or arranged in a different pattern, than the array of aspiration conduits **14** extending through the aspiration manifold **10**. For instance, the assembly can be adapted for transferring liquid from a non-linear array of reservoirs to a linear array of dispense manifold orifices, and vice-versa. Similarly, the assembly can be adapted for transferring liquid from a rectangular array to a radial array, and vice-versa. As used herein, the term "array" is also intended to encompass a plurality of reservoirs, conduits, orifices or test sites having non-symmetric patterns or variable pitches. The printhead can also be adapted for being rotated during operation. Accordingly, the relative orientations of the aspiration manifold conduits **14** and dispense manifold orifices **106** can be varied.

Significantly, the manifold structure of the present invention enables liquid to be transferred from an array of sample reservoirs having a minimum pitch on the order of millimeters to an array of orifices having a minimum pitch on the order of microns. For instance, we have employed the present invention to transfer reagents from conventional microtiter plate wells having a pitch in the range of about 2.25 mm to about 9.0 mm, to test sites on a solid state substrate having a pitch in the range of about 1 micron to about 10,000 microns.

Auxiliary apparatus **30** may be provided for cleaning and purging the various fluid transfer conduits of the assembly. For example, a gas pressure conduit **32** and cleaning liquid conduit **34** may be fluidly connected, via conduit **38**, to switching valve **22**. Preferably, the introduction of cleaning/purging fluids into the system is controllable through a suitable valve **36**, such as solenoid, shear, flat face and pinch valves, actuated by mechanical, electrical or pneumatic means. Preferably, purging apparatus **30** is fluidly connected to valve assembly **21** through a modular connector **90** integrated into the valve assembly. Alternatively, purging apparatus **30** can be directly integrated into dispense manifold switching valve **22**.

Referring now to FIG. **3**, an aspiration manifold assembly **10** is illustrated in accordance with a preferred embodiment of the present invention. The aspiration manifold includes an array of aspiration subassemblies extending through a base plate **17** and adapted for being received by a corresponding array of liquid filled reservoirs **52** formed in a source plate **50**. In the preferred embodiment of the invention, the reservoirs comprise reagent-filled wells formed in a microtiter plate. Each subassembly includes a guide member **16**, a cap member **18**, a pressure conduit **12** and an aspiration conduit **14**. Pressure and aspiration conduits **12** and **14** preferably comprise narrow-bore tubing constructed from plastic, metal or glass.

Guide member **16** has a first end adapted for being mechanically fastened to base plate **17**. Preferably, mechanical fastening is achieved by providing guide member **16** with a first threaded end for easy mechanical insertion, i.e., twisting, into the base plate. It will be apparent to one skilled in the art that alternate mechanical fastening means are possible. Regardless of the fastening means employed, it is important that the guide member snugly engages the base plate to prevent movement of the guide member during operation of the assembly. When fully inserted, a second flanged end **11** of the guide member extends downward from a lower surface of the base plate. Guide member **16** also has a pair of longitudinally-extending channels (not shown) for snugly-receiving the plastic tubing.

Cap member **18** has a first end adapted for engaging the flanged end **11** of guide member **16**. An opposite second end of the cap member has a tapered outer surface **19** for engaging the perimeter of one of the liquid-filled reservoirs **52**. Preferably, the cap member is manufactured from a suitable polymer, rubber or other compressible material. In this manner, as aspiration manifold **10** is seated onto microtiter plate **50**, the cap members act to seal the reservoirs. Each cap member **18** is provided with longitudinally-extending channels aligning with the channels in a corresponding guide member **16** for receiving the plastic tube conduits. Pressure conduit **12** extends completely through cap member **18**, but terminates above liquid level **56**. Aspiration conduit **14** extends through cap member **18**, terminating at a position below liquid level **56**. In operation, aspiration manifold is seated onto microtiter plate **50** such that cap members **18** seal against the perimeter of corresponding wells **52**. Subsequently, the wells are pressurized by applying pneumatic pressure through pressure tubing **12**, thereby urging the transfer of liquid reagent **54** from the wells **52**, through aspiration tubing **14**, toward the dispense manifold **20**.

Although the various elements of the aspiration manifold assembly are illustrated as individual sub-components, they can be combined. For instance, in an alternate embodiment of the present invention, cap member **18** and guide member **16** comprise a unitary component, for example, molded from plastic or machined from metal. Taking this integration a step further, in yet a further embodiment of the invention, cap and guide members **18** and **16**, respectively, are integrated into base member **17** such that the entire aspiration manifold assembly, except for the tubing, comprises a single, unitary component. For instance, the entire aspiration manifold assembly can be molded from a suitable polymer or machined from a suitable metal.

Referring now to FIG. **4**, an alternate embodiment of the aspiration manifold has a single pressure inlet **12** for pressurizing the wells **52**. In lieu of individual cap members for sealing each of the wells, a gasket member **23**, preferably constructed from a suitable polymer, rubber or other compressible material, is disposed along the periphery of the underside of base plate **17**. In this manner, as aspiration manifold **10** is seated onto microtiter plate **50**, sealing member **23** seals against the periphery of plate **50**. Individual aspiration conduits **14** extend into each of the liquid-filled reservoirs for transferring reagent from the wells to the dispense manifold.

As illustrated in FIG. **2**, in the preferred embodiment of the present invention, modular connectors **90** provide fluid connection between the valve assembly **21** and various subassemblies of the dual manifold system. It will be apparent to one skilled in the art of connectors that myriad different modular connector designs are possible for use

with the present invention. Referring now to FIG. 5, a preferred connector design will now be described. For the purpose of simplicity, the following discussion is directed specifically to a single modular connector located between aspiration manifold 10 and valve assembly 21. However, all of the modular connectors 90 can have similar structures and operate in a similar fashion. Modular connector 90 includes female and male components, 92 and 94, respectively. Channels 96 formed in female subconnector 92 are adapted for releasably engaging integral connector tips 95 extending from male component, or plug, 94. Preferably, the individual channels/fittings 96 of the female unit have integral sealing elements 99, such as ribs, for preventing the leakage of fluids passing through the connector. During operation of the assembly, male connector 94 is fitted in female connector 92 such that the ends of tips 95 contact integral stop mechanisms 98. The geometry of the connectors may vary. However, as illustrated in FIG. 6, the individual connector units are preferably designed much like a standard electrical connector.

In alternate embodiments of the present invention, auxiliary assembly features are included for improving registration and alignment of reagent samples dispensed on the target substrate and/or for improving quality control. For instance, in one alternate embodiment of the invention, fiducial pins and/or marks are integrated into the target substrate and/or microtiter plate. The integrated features can be directly sensed by a conventional vision system for ensuring proper alignment and orientation during operation. Alternatively, the integrated features can be designed for interaction with position-sensitive detection electronics. In a further embodiment of the present invention, detection means are provided for detecting the passage of a droplet of reagent from a dispense orifice 106. For instance, referring now to FIG. 7, photodiode 100 and photodetector 102 devices can be positioned proximate to a dispensing orifice 106 to sense the passage of a droplet. Alternatively, electronic conduction-based sensors can be incorporated directly into the dispense manifold, for example, by applying a conductive coating to portions of the inner wall of each orifice 106 and monitoring electrical current therebetween.

Referring now to FIGS. 1-7, the operation of the dual-manifold assembly of the present invention will now be described. Initially, a source plate 50, such as a microtiter plate, is advanced on a feeder track 70 until it is properly positioned beneath aspiration manifold 10, and target substrate 60 is advanced on track 72 until it is properly positioned beneath dispense manifold 20. An optional alignment step may be performed to ensure proper positioning and orientation of the source plate, the target substrate or both. With the source plate and aspiration manifold adequately aligned, aspiration manifold 10 is vertically-actuated until it is seated onto source plate 50 such that an air-tight seal is formed between the manifold 10 and the plate 50. In the preferred embodiment of the invention (FIG. 3), cap members 18 of the aspiration subassemblies form a seal over the reservoirs. Where the alternate embodiment of the aspiration manifold assembly is employed (FIG. 4), the aspiration manifold 10 is vertically-actuated until gasket 23 seals against the periphery of source plate 50. Preferably, during operation, the aspiration and dispense manifolds are limited to vertical movement.

With the aspiration manifold properly seated upon the source plate, pressure is introduced to the reservoirs from pressure source 40, via conduit(s) 12, to effect liquid transfer through conduits 14 toward dispense manifold 20. Preferably, once liquid transfer to the dispense manifold has

been effected, switching valve 22 is actuated to disable fluid connection between the dispense manifold and the aspiration manifold, while enabling fluid communication between the dispense manifold and liquid ejection means 28. If necessary, dispense manifold 20 can be vertically positioned to a desired height above target substrate 60. Subsequently, a force, such as a pressure pulse, is communicated to the dispense manifold for a period of time to effect the ejection of a precise volume of liquid from the dispense manifold through orifices 106 to test sites 64 on target substrate 60. Preferably, the dispense manifold is maintained at a constant position during operation of the assembly.

Preferably, a complete array of test sites are printed contemporaneously, and tracks 70 and 72 are each advanced after the printing of a single array. However, liquid transferred from a single array of reservoirs may be adequate to dispense multiple arrays or sub-arrays of test sites. In that instance, printing can comprise repeatedly advancing test track 72 to reposition an array or sub-array of test sites beneath dispense manifold 20, while maintaining the position of feeder track 70. Conversely, other applications may require maintaining the position of test track 72 while advancing feeder track 70.

It will be apparent to one skilled in the art that further variations of the methods described herein are possible without departing from the scope of the invention. For instance, where track 70 and/or track 72 are adapted for movement in multiple directions, the method can include repositioning the reservoirs and/or test substrate via movement of the tracks 70, 72, such that the tracks are not "advanced". Similarly, where the printhead is adapted for being rotated, the step of positioning the dispense manifold can include the sub-step of rotating the printhead.

In an alternate embodiment of the present invention, the method includes the additional step of detecting the passage of a droplet, or volume, of liquid from the array of dispense manifold orifices to the array of test sites. In a further embodiment of the invention, the method includes periodically purging fluid transfer conduits of the assembly with a cleaning fluid such as water.

While the preferred embodiments of the invention have been illustrated and described, it will be clear that the invention is not so limited. Numerous modifications, changes, variations, substitutions and equivalents will occur to those skilled in the art without departing from the spirit and scope of the present invention as described in the claims. For instance, it will be apparent to one skilled in the art that various modifications to the preferred valving arrangement are possible.

We claim:

1. A method for transferring liquid reagent from a first test site to a second test site on a target substrate using a dual-manifold assembly, comprising the steps of:

positioning at least one source reservoir relative to an aspiration manifold, said source reservoir having at least one reagent therein, said aspiration manifold having at least one aspiration conduit;

positioning said target substrate relative to a dispense manifold having at least one channel terminating at an orifice wherein at least one of said dispense manifold channel and said aspiration conduit number at least two;

seating said aspiration conduit onto said source reservoir;

applying pressure to at least a first location to force said source reservoir to flow said reagent via said aspiration conduit to said dispense manifold; and,

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applying pressure to at least a second location, said second location different from said first location, to force said reagent in said dispense manifold channel to eject a desired volume of said reagent to said second test site.

2. The method as recited in claim 1, further comprising the step of checking the alignment of said target substrate prior to said applying pressure to said second location.

3. The method as recited in claim 1, further comprising the step of detecting the passage of a volume of reagent from said orifice to said second test site after applying pressure at said second location.

4. The method as recited in claim 1, wherein said second location is disposed between said aspiration and said dispense manifold, further comprising the step of purging at least a portion of said aspiration conduit with a purging gas or a cleaning solution, said purging gas or said cleaning solution introduced at said second location.

5. The method as recited in claim 1, wherein said applying pressure at said second location step comprises communicating a pressure pulse in the range of about  $6.9(10)^3 \text{ N/m}^2$  to about  $138(10)^3 \text{ N/m}^2$ , for a period of time in the range of about  $(10)^{-6}$  seconds to about  $(10)^{-2}$  seconds.

6. The method of claim 1, wherein said dispense manifold channel is spaced apart from said reagent in said second test site during an entire duration of said method.

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7. The method of claim 1, further comprising the step of disabling fluid connection between said dispense manifold and said aspiration manifold.

8. The method of claim 1, wherein said at least one aspiration conduit comprises a plurality of aspiration conduits, said applying pressure at said first location step comprising pressurizing at least one of said plurality of aspiration conduits differently as compared to any of the other of said plurality of aspiration conduits, wherein different pressures or times at pressure can be selectively applied to respective ones of said plurality of aspiration conduits.

9. The method of claim 1, wherein said at least one dispense manifold channel comprises a plurality of dispense manifold channels, said applying pressure to said second location step comprises pressurizing at least one of said plurality of dispense manifold channels differently as compared to any of the other of said plurality of dispense manifold channels, wherein different pressures or times at pressure can be selectively applied to respective ones of said plurality of dispense manifold channels.

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